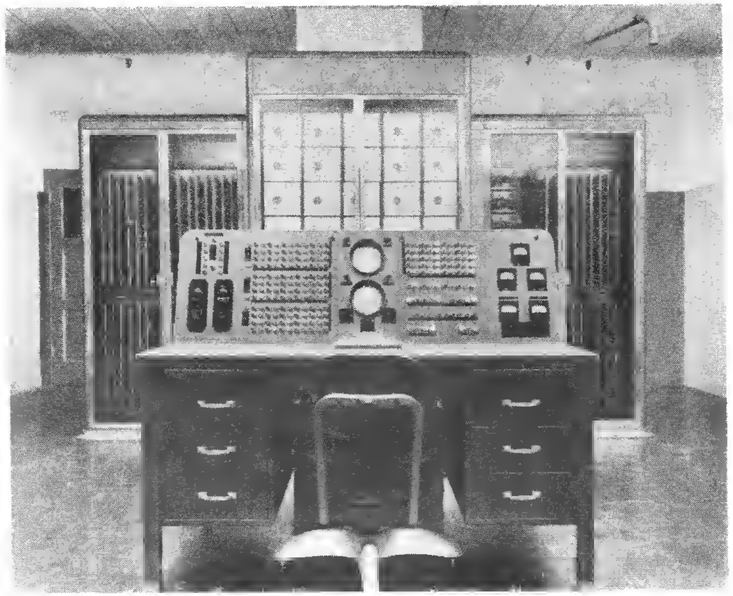
S W A C

NATIONAL BUREAU OF STANDARDS
WESTERN AUTOMATIC COMPUTER



A brief description of SWAC on its dedication, and of the program of the NBS Institute for Numerical Analysis

U. S. Department of Commerce
National Bureau of Standards
Institute for Numerical Analysis
August 1950

Foreword

The National Bureau of Standards Western Automatic Computer was sponsored by the Office of Air Research of the United States Air Force, for use by the NBS Institute for Numerical Analysis in long-range mathematical research as well as on present-day problems originating with the Air Force, Air Force contractors, and other governmental agencies. The NBS Institute is one of the four sections of the Applied Mathematics Laboratories of the National Bureau of Standards. Two primary functions of the Institute are to carry on long-range fundamental research in various fields of mathematics related to the effective use of automatic digital computing machinery, and to provide computing services to Western scientific laboratories. The research program of the Institute is financed principally by the Office of Naval Research; the computation unit is financed chiefly by the Office of Air Research. The completion of the SWAC greatly improves the computing facilities of the Institute and increases the effectiveness of the research program. This brochure marks the formal dedication of the SWAC.

E. U. CONDON, *Director*

Symposium on applications of digital computing machinery to scientific problems. The purpose of this symposium is to interchange information on various scientific problems which are now being studied by West Coast laboratories and universities, and to which high-speed automatic digital computing machinery may be applicable.

August 18, 1950

10 a.m. - 12:15 p.m.

2 p.m. - 4:30 p.m.

Room 147, Business Administration-Economics Building, U.C.L.A.

10: a.m. **Introductory Remarks**

The Honorable E. U. CONDON, *Director*, National Bureau of Standards

10:15 a.m. **Morning Session**

E. P. LITTLE, Office of Air Research, U.S.A.F., *Chairman*

Initiation of an Airplane Turn

ELLIS LAPIN, Douglas Aircraft Company, Inc.

Problems in Water Entry Ballistics

B. P. COOPER, U. S. Naval Ordnance Test Station, Pasadena

Reduction of Measurements in Free Flight Testing of Missiles.

ELMER GREEN, U. S. Naval Ordnance Test Station, Inyokern.

Solution of Games by Iterative Processes.

PAUL ARMER, RAND Corporation.

Nuclear Reactor Physics Computations

SIDNEY H. BROWNE, North American Aviation, Inc.

The Use of Iterative Processes in the Solution of Partial Differential Equations

STANLEY FRANKEL, California Institute of Technology

A Problem of the Naval Air Missile Test Center

L. H. CHERRY, U. S. Naval Air Missile Test Center, Point Mugu

2:00 p.m. **Afternoon Session**

H. D. HUSKEY, National Bureau of Standards, *Chairman*

Some Problems in Mathematical Statistics

JERZY NEYMAN, University of California, Berkeley

An Iterative Construction of the Optimum Sequential Decision Procedure when the Cost Function is Linear

LINCOLN MOSES, Stanford University

Problems in Pure Mathematics

D. H. LEHMER, University of California, Berkeley

On the Green's Function of the Clamped Plate

PAUL R. GARABEDIAN, Stanford University

Perturbations of a Satellite Rocket

SAMUEL HERRICK, University of California, Los Angeles

Physics Research Problems at Stanford Susceptible to Automatic Computation

PAUL H. KIRKPATRICK, Stanford University

An Astronomical Problem
LELAND E. CUNNINGHAM, University of California, Berkeley

Automatic Computation in Rocket Engine Research
H. L. COPLEN, Aerojet Engineering Corp.

OPEN HOUSE
August 19, 1950

Demonstration of SWAC
10 a.m. - 12:00 noon
2 p.m. - 4:00 p.m.

DESCRIPTION OF THE NATIONAL BUREAU OF STANDARDS WESTERN AUTOMATIC COMPUTER

The National Bureau of Standards Western Automatic Computer (SWAC) is an extremely fast automatically-sequenced electronic digital computer. Commercially-produced cathode ray tubes are used as the storage element in the high-speed memory unit. The computer is compact, occupying about 50 square feet of floor space. The development and construction of the computer was carried on at the NBS Institute for Numerical Analysis, where the SWAC is to remain as a permanent addition to the Institute's computing facilities.

The conception of this computer project took place at the October 19, 1948 meeting of the Applied Mathematics Executive Council held at the National Bureau of Standards, Washington, D. C. At this meeting the Office of Air Research of the United States Air Force agreed to sponsor the computer. In December 1948, H. D. Huskey reported for duty at the NBS Institute for Numerical Analysis after his transfer from the National Bureau of Standards, Washington, D. C. The first few months were spent in procuring necessary machine shop equipment and in recruiting a staff for the newly established INA Machine Development Unit. The study of the general machine organization and logical system was carried on also during this time. The development of the machine system, circuitry, and construction techniques proceeded simultaneously as much as possible with the actual construction of the machine. The assembly of the computer was completed in July 1950.

The computer proper consists of three major parts: an arithmetic unit, a memory unit and a control unit all of which are encased in a single cabinet. Together with these units, three other essential

parts compose the SWAC compnter system; the input-ontpnt unit, the operating console, and the power snpply.

The arithmetic unit operates in a parallel mode, that is, all the digits of a number are operated on simultaneously, thus helping to make possible extremely high-speed in computation. The SWAC is capable of adding pairs of ten-digit numbers, in a binary representation, at the rate of 16,000 per second, and it can mnltiply snch numbers at the rate of 2500 per second. These rates include the time it takes for the machine to receive the numbers from the memory, perform the reqnired arithmetic operations upon them, return the resnlt to the memory, and obtain the next instrnction from it.

The SWAC performs the following operations through the insertion of a single command word:

1. Addition
2. Snbtraction
3. Mnltiplication Exact
4. Mnltiplication Ronnded-off
5. Comparison (both Normal and Absolnte)
6. Extract
7. Input
8. Output

There are also three special commands in addition, snbtraction, and rounded-off mnltiplication which permit the transferring of the control to some point in the memory not in the regular seqnence, thus taking the place of a transfer of control, or nnconditional transfer, command.

The comparison command determines the course of the computation depending upon the relative sizes of two numbers; thus, the machine may be said to possess a degree of choice. Extract divides numbers up into parts which the computer can then handle in different ways. Therefore, after an instrnction or number has been inserted in the computer, an arbitrary part of it can be deleted, if desired, and treated independently of the other part. Extract also provides for obtaining the logical prodnct of two numbers and shifting the resnlt an arbitrary amount.

Two principles were followed in deciding upon this list of basic commands. First, that there should be as few commands as practical in order to simplify the electronic circuitry of the computer, and to permit as speedy constrnction as possible. The second principle was that the commands shonld be as general as possible, thus eliminating the need for a greater number of commands. For example, the extract command permits the nse of any factor whatsoever, and the selections in case of overflow are completely general.

Other arithmetic operations which need to be performed are accomplished by sequences of commands known as rontines and subroutines. Rontines and sub-routines can be stored in the memory unit and be called from there into action by the use of special instructions. This procednre simplifies the process of preparing problems for the compnter.

Problem preparation is further simplified by the storing of less frequently nsed routines on paper tape for insertion into the computer as needed. Thus, what might be thonght of as a "library" of routines can be established for use by the machine whenever a problem

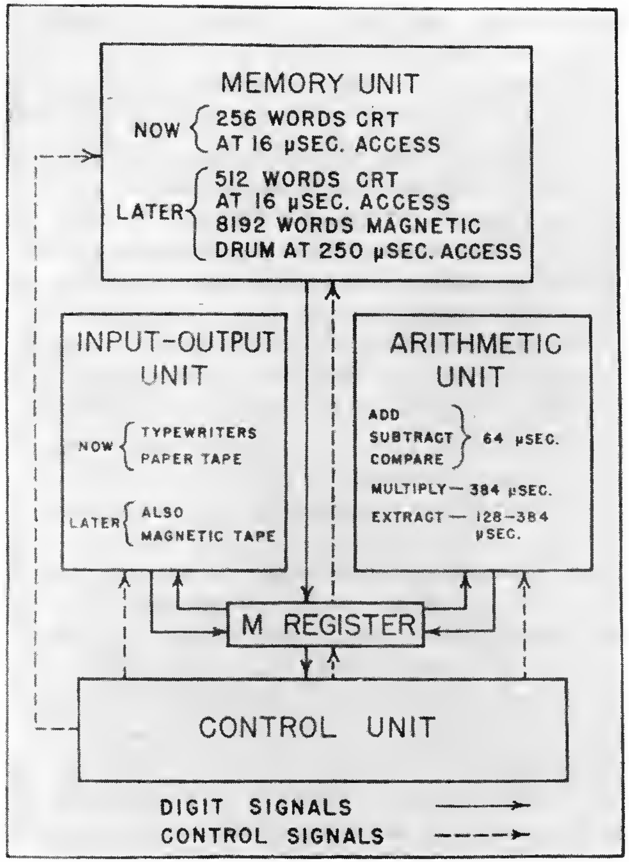


Figure 1. Simplified Block Diagram of the SWAC

Figure 2. Memory Monitoring Tube

needs to be solved in which one of these standard routines can be used.

The cathode ray tube high-speed memory operates on a principle discovered by Professor F. C. Williams of Manchester University, England. This memory unit is parallel with (initially) thirty-seven binary digits per word or number. Words are available from it in only 16/1,000,000 of a second (access time). This type of memory requires regeneration, which is carried on during alternate eight-microsecond intervals. During the other eight-microsecond intervals, operands are transferred from the memory to the arithmetic unit, results are transferred back to the memory, and the next command is transferred to the control unit.

In the cathode ray tube type of memory the individual digits of the information are stored in the form of spots of charge which exist over small areas of the inside of the tube face. These spots are arranged in the manner of a matrix on the face of the tube. Two different charge distributions, providing the required number of states needed to describe the appropriate digit of the binary system, can be produced at each spot. These spots may have either a dot or a dash appearance, the dot corresponding to a "0" and the dash to a "1". Figure 2 shows how these spots of charge appear on the monitoring tube of the console. Here the dot-dash pattern on any one of the memory tubes (selected by a switch) is displayed as zeros and ones.

The final plans for the SWAC include an intermediate-speed auxiliary memory consisting of a magnetic drum, and a magnetic tape unit to serve as a slow-speed auxiliary memory. The magnetic drum for this purpose was construtted at the University of California at

Berkeley under the direction of Professor Paul Morton. At present the necessary circuitry and adjustments are being constructed at the Institute to enable it to be incorporated into the SWAC memory system. The drum has a relatively large storage capacity of 8192 words, and an average access time of 8/1000 of a second. The slow-speed memory will have a capacity of about 180,000 words and a word from it will be available on the average in 3¼ minutes. These three different types of memory units incorporated into one memory system will make possible the use of the SWAC for problems of great length and complexity.

The control unit causes all the various units of the computer to operate together. It receives commands from the memory, and supplies the appropriate signals to all other units causing them to carry out the particular instructions involved.

The power for operating the SWAC comes from the regular power lines via a motor generator set. The motor generator set gives isolation from line voltage fluctuations which might upset the computer.

The actual operation of the SWAC takes place from the console. The console is a desk with specially built panels mounted on its top surface. Operation is controlled by means of switches.. Neon lights, together with the memory monitoring tube and a cathode ray tube which shows each spot in the memory which is currently being referred to, indicate to the operator what is taking place inside the machine.

Flexowriter units are used at present as the input and output devices. A flexowriter unit consists of electromatic typewriters, a teletype tape reader and a teletype tape perforator. It is planned to supplement

these units as soon as possible with a magnetic tape system.

A problem can be set up for solution on the SWAC simply by the insertion of a set of instructions through the input-output unit.

The SWAC is automatically-sequenced which means that it receives its instructions from the same memory as it does its numbers. This is in contrast to earlier large-scale computers which received their instructions from cards or from paper tape. The speed of such computers is limited by the rate at which the tape or cards can be read, which is only a few numbers per second. The SWAC has an extremely fast arithmetic unit, and in order to utilize this speed effectively, instructions must be available to the computer at rates corresponding to the computation time. To accomplish this, the instructions and numbers are all stored together in a quickly accessible high speed memory. Instructions are distinguishable from numbers only by the way the machine makes use of them, as a result of the manner in which the mathematician has prepared the problem for the calculator.

Components which are mass-produced commercially were used wherever possible in the SWAC, since they are expected to be more reliable, easily replaced, and relatively economical.

All circuitry in the SWAC is on plug-in units, and there are spare plug-in units for about 80% of the chassis in the computer. This means that in case of the failure of some component the faulty chassis can be removed and replaced by a spare one. This type of construction, together with certain borderline checking facilities will, it is hoped, mean a small percentage of down-time for the computer.

The SWAC will be used to solve the research problems of the Institute, as well as the problems of the United States Air Force and their contractors, and of other governmental agencies. The research computing will include such problems as matrix inversion, finding characteristic values of matrices, solution of simultaneous linear equations, finding complex roots of algebraic equations, etc. A problem in pure mathematics for which it is planned to use the SWAC is the computation of zeros of the Riemann zeta-function. Computation of more roots would lead to further information on the distribution of primes and might provide the key steps for a proof or disproof of this famous conjecture.

A high-speed general purpose computer such as the SWAC can also be used in logical computation. For example, a project is at present underway at the Institute whose purpose it is to study the possibilities of automatic substitution-translation, particularly in relation to the translation of foreign languages. This project is investigating such items as word order, sentence structure, and word frequency, using the German language as a model, to attempt to determine what can be done towards rearranging sentences and so forth, in order to obtain as clear a translation as possible. The present goal is a rough but readable translation which can be scanned quickly by scientists.

The design and construction of large-scale automatic electronic digital computing machines has been a recent development that has put a powerful new tool in the hands of scientists. The United States government early recognized the potentialities of such machines and sponsored several projects through its various agencies. The National Bureau of Standards took an active part, first through the issuance of development contracts to commercial companies, and later as an evaluator of various computer systems proposed by several commercial companies interested in developing machines of this type.

In 1948 the National Bureau of Standards was requested to design and construct two automatic computers of different types. Both machines were sponsored by the Department of the Air Force and were to be used to augment the computing facilities of the Bureau's computation laboratories in Washington D. C. and Los Angeles. The resulting machines have now both been completed; the National Bureau of Standards Eastern Automatic Computer (SEAC) was dedicated in Washington, D. C. on June 20 of this year. SEAC is of serial mode and employs mercury delay lines as the principal type of memory device. The National Bureau of Standards Western Automatic Computer (SWAC), now being dedicated at the NBS Institute for Numerical Analysis at Los Angeles, is of parallel mode with standard cathode ray tubes composing its high speed memory.

The development and construction of these two computers represent one aspect of the NBS program relative to digital computers. This program has four principal phases: (1) computer design and construction, (2) fundamental research, (3) technical services,

and (4) engineering development. Both mathematics and electronics are involved, and accordingly the work is carried on in both the Bureau's Electronics Division and in its National Applied Mathematics Laboratories.

The fundamental research includes basic studies in numerical analysis, programming and coding techniques, and electronic development, with the objective both of improving the computing machines and of making the most effective use possible of the machines now in existence.

Technical services for other government agencies represent an important phase of the program. Consulting services in the computer field are available to Federal agencies, and the Bureau has assumed, when requested, a more active role as technical coordinator on computer contracts between Federal agencies and commercial companies. Five of these contracts are in force at present as follows:

(a) The Bureau of the Census machine to be used in the tabulation and computation of statistical information.

(b) The Air Comptroller machine for program planning problems.

(c) The Army Map Service computer for use in calculations arising in the adjustment of maps.

(d) The Office of Air Research machine for the handling of engineering computations.

(e) The Office of Naval Research computer to be used to increase the computing facilities of the Bureau.

Engineering development is furthered by the actual

construction of working models such as the SEAC and the SWAC. By developing two machines of totally different design, the relative advantages and limitations both of the many different types of electronic elements which compose these computers and also of their various design features can be accurately noted. The results of these studies, when available, will be at the disposal of other laboratories interested in constructing, or having constructed for them, an automatic digital computer.

A vital role in the Bureau's computer program is being played by the Institute for Numerical Analysis which is a section of the National Applied Mathematics Laboratories. The Institute is located on the campus of the University of California at Los Angeles. The Institute was established in 1948 for the purpose of carrying on mathematical research which would advance the art of computing and increase the utilization of automatic computing machinery through the evolution of numerical methods better suited to the new type computing equipment. The research program at the Institute is financed chiefly by the Office of Naval Research. In addition to the research staff the NBS Institute has a computation unit and a machine development unit. These two units are financed at present principally by the Department of the Air Force.

The machine development unit designed and constructed the SWAC, and is now engaged in developing improvements to be incorporated in the SWAC system at a later date.

The computation unit of the Institute serves as a proving ground for the problems of the research staff. Its services are also available for the use of other governmental agencies and governmen-

tal contractors. The addition of the SWAC to the equipment of the computation unit increases the scope of problems that can be efficiently handled by the Institute, as the SWAC has a much greater internal storage capacity and operates at a much higher speed than any of the present equipment.

The preparation of problems for solution on a computer such as the SWAC is very important, since a great deal of skilled mathematical effort is required, both in the programming and in the coding of most problems suitable for a high-speed computer. Programming includes the choosing of methods, the order in which the steps of the calculation are to be taken, and decisions about bounds, accuracy, checks and so forth. Coding consists of transcribing the previously prepared program into the explicit operations which the computer is to perform.

For this matter of problem preparation the Institute is exceptionally well-prepared, due to its research and computation unit staffs. Problems of other organizations, when submitted for solution on the SWAC, will be coded by the Institute, and on request, assistance will also be given in the programming of these problems.